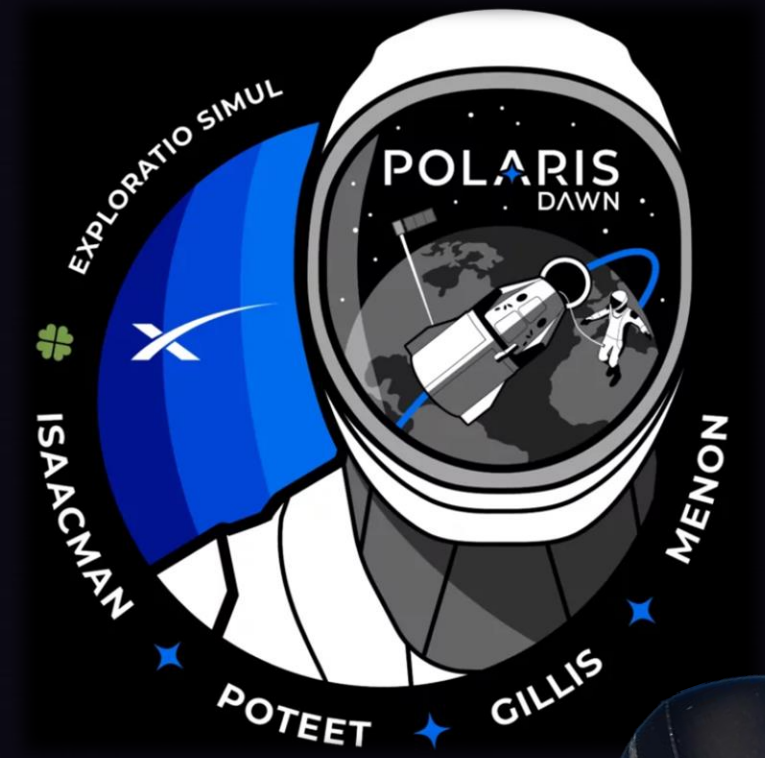

IMAGING-BASED HUMAN PHYSIOLOGY RESEARCH AND INNOVATION IN EARLY SPACEFLIGHT: POLARIS DAWN MISSION

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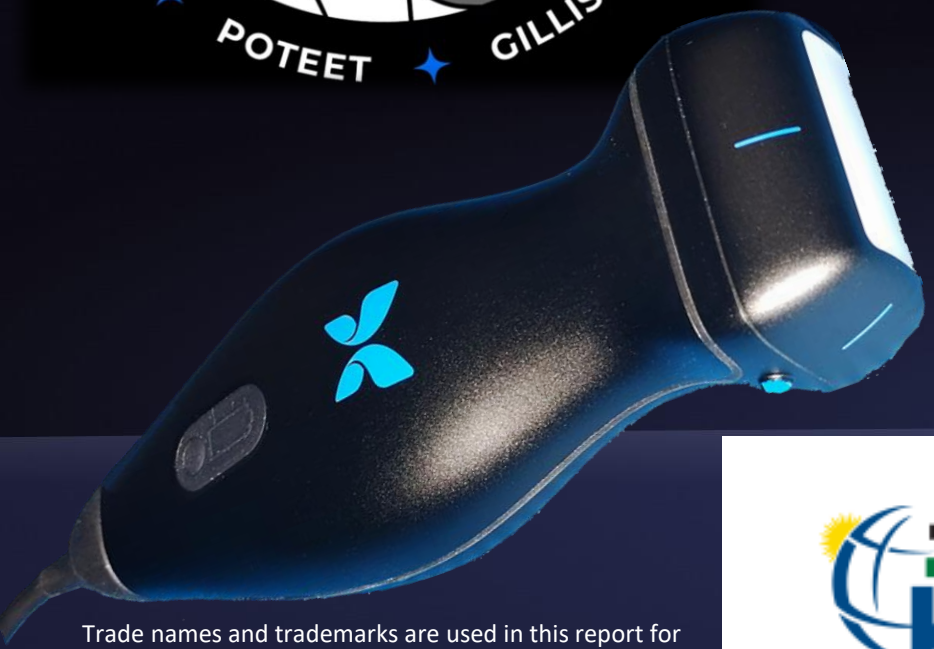
V. Perizes, J. Scheurle (Level Ex)

M. Rosenberg, J. Mateus (SpaceX)

R. Mendez, J. Martin (Butterfly Network, Inc.)

J. Wu (TRISH)

HRP Investigators' Workshop February 8, 2023



KBR

LEVEL EX

SPACEX

TRANSLATIONAL RESEARCH INSTITUTE FOR SPACE HEALTH™

OBJECTIVES

- **Physiological data**
  - Early inflight period historically unobtainable
  - Spacefaring population becoming more diverse
  - Many spaceflight changes still poorly understood, risks unmitigated
  - Private spaceflight offers more rapid access to higher n
- **Autonomous procedures**
  - Communication delays and outages
  - Transition to new training paradigms
  - Terrestrial application (remote medicine, DOD)
  - Leverage new hardware and software
  - Concepts extend beyond medical realm (medical ultrasound as a use case)

SPECIFIC AIMS

1. Measure urinary bladder function in microgravity
2. Measure filling and flow patterns of the internal jugular vein
3. Collect data on the effectiveness of just-in-time training & novel delivery formats
4. If present, document venous gas bubbles following reduction in cabin pressure

PROJECT SUMMARY

APPROACH:

- Use of advanced tech in a point-of-care device for research
- Minimum crew time utilization, complete autonomy in-flight
- A range of procedural challenge / complexity
  - Guidance by just-in-time (JIT) modules on iPhone 12*
  - Use of available AI-based automation (bladder)
- **All procedures are relevant to a recognized spaceflight risk**

TECHNOLOGY / PAYLOAD:

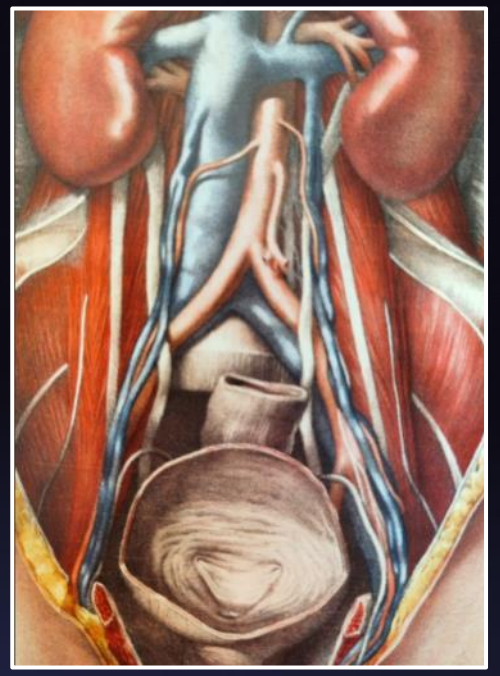
Butterfly iQ+ ultrasound system with mobile platform - iPhone 12/iPad mini6

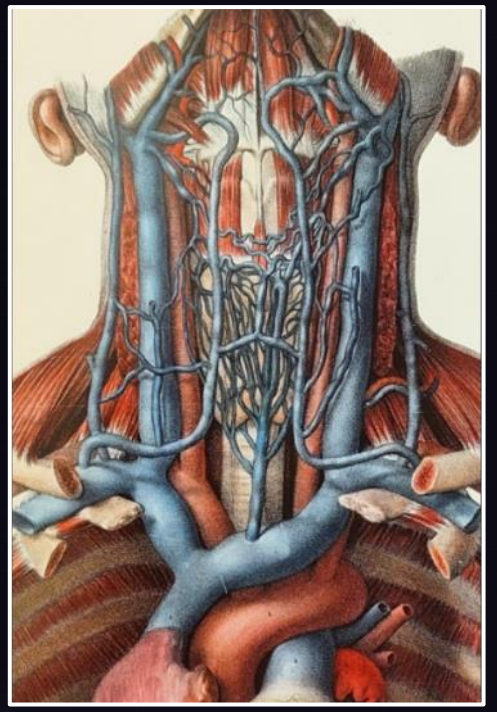
Single-probe capacitive transducer array on silicon chip

Zoll ResQGARD® Impedance Threshold Device – ITD 7 (7 mm Hg)

PHYSIOLOGY

1) **Urinary bladder** function in microgravity
2) **Internal jugular vein (IJV)** response to microgravity with and without inspiratory resistance
3) **Bubble detection** following pressure reduction (femoral vein, carotid artery)

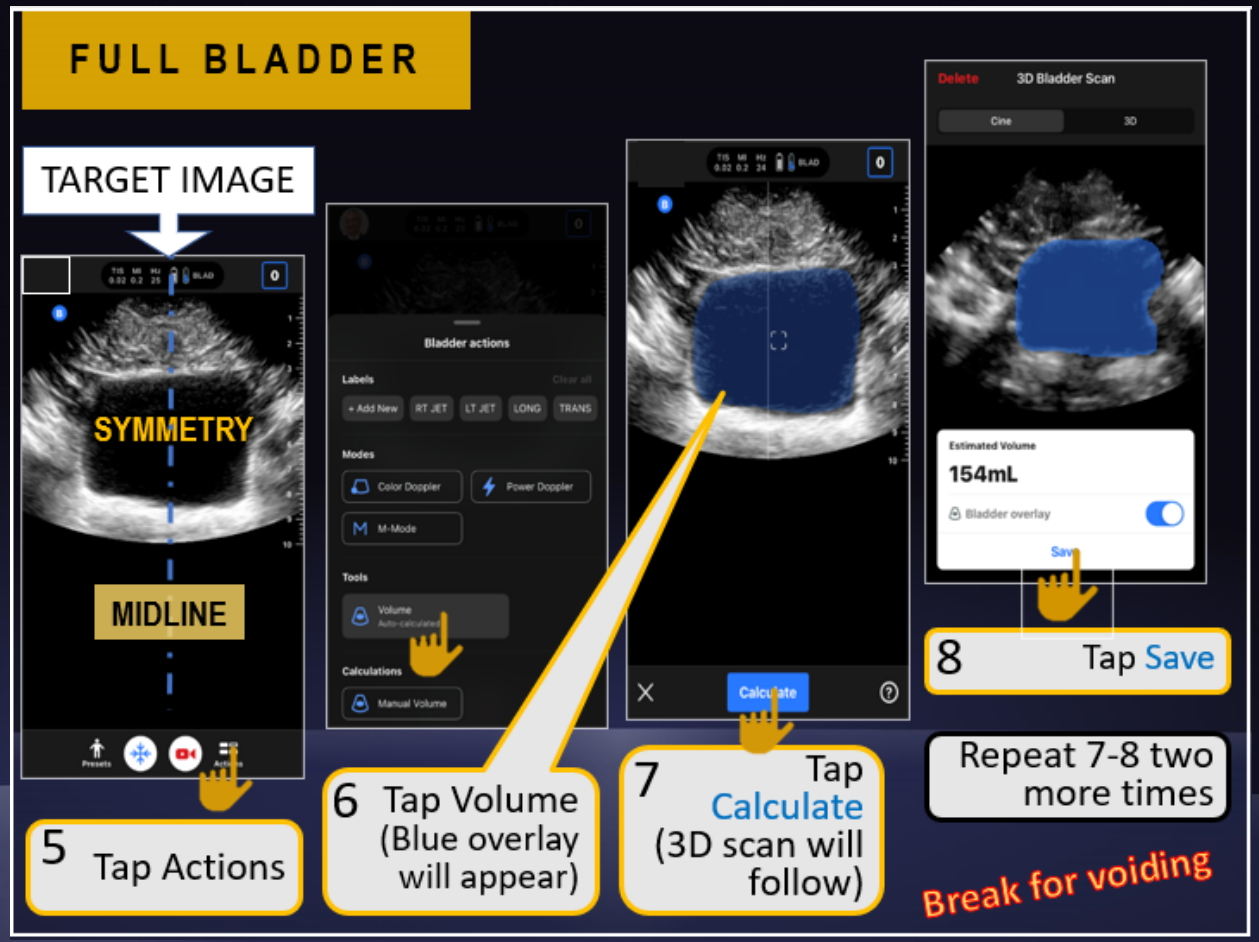




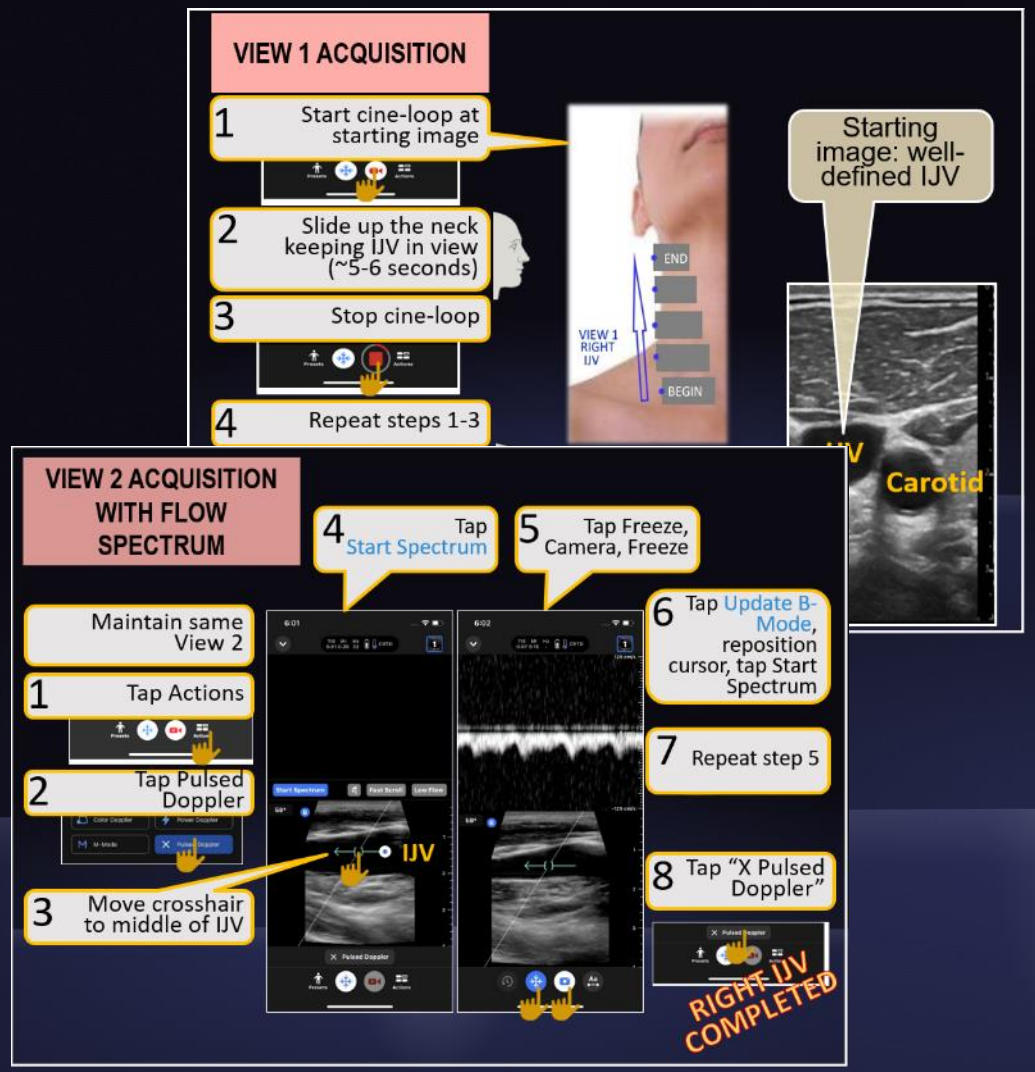
Images from Bourgery and Jacob, *Atlas of Anatomy and Surgery*, 1831

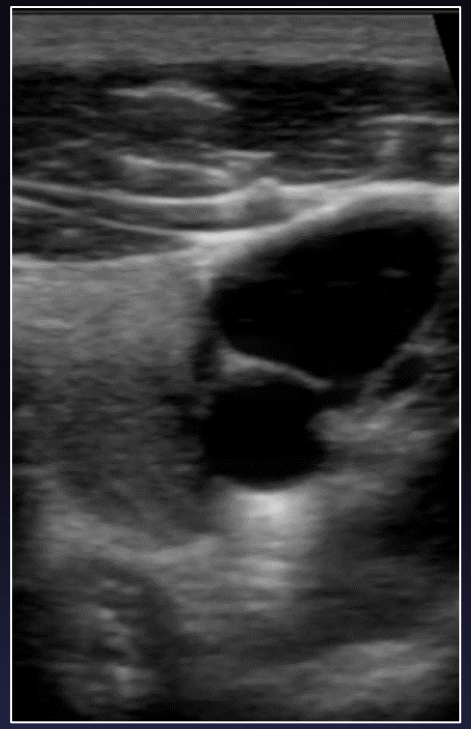
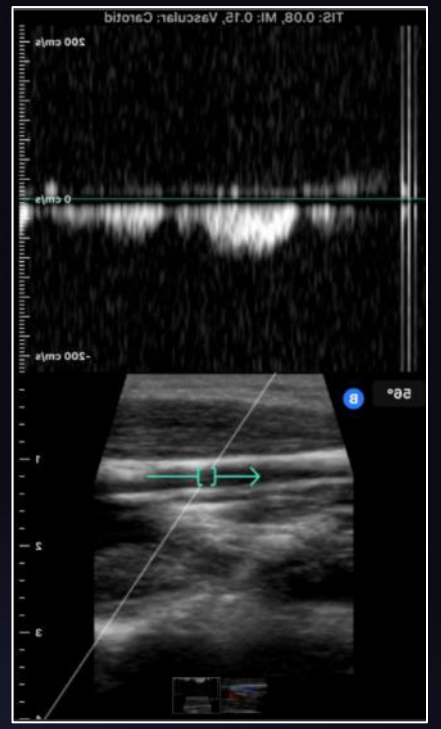
URINARY BLADDER FUNCTION

- Supports medical procedure
  - urinary retention
- Limited I4 data already being used to inform exploration systems



IJV- MODES AND MEASURES

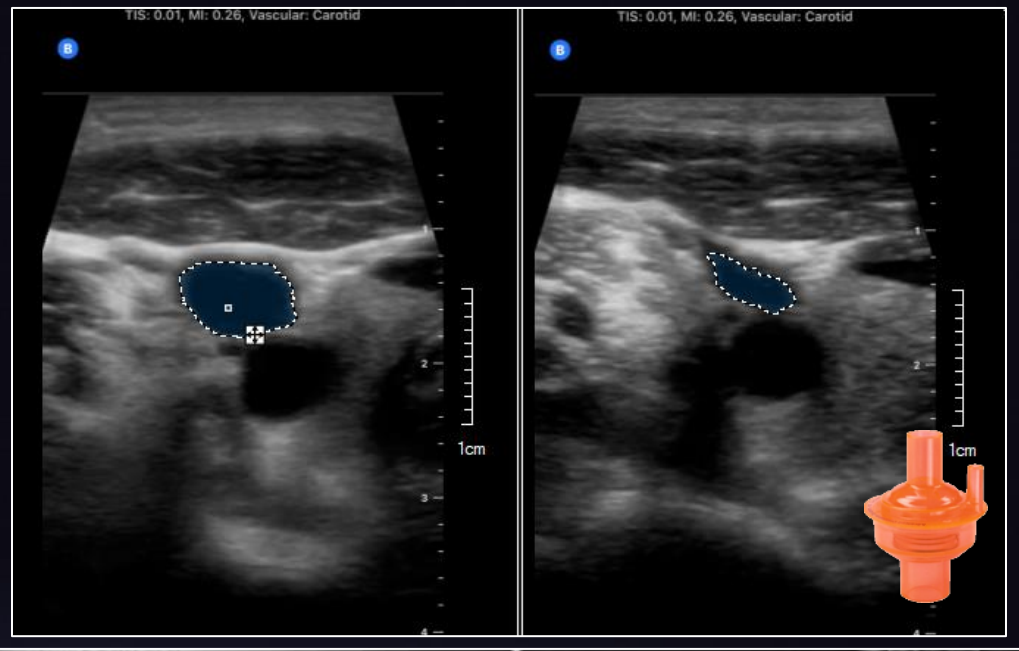


B-MODE	COLOR DOPPLER	SPECTRAL DOPPLER
		
• Cross-sectional areas • Perimeter • Clots if present • Spontaneous contrast (cell aggregation = rise in viscosity) • ITD effect on filling	• Flow direction • Flow spontaneity • Flow uniformity • Flow voids and irregularities	• Flow direction • Peak velocities in cm/s • Flow laminarity • Flow type (central type or "peripheralized")

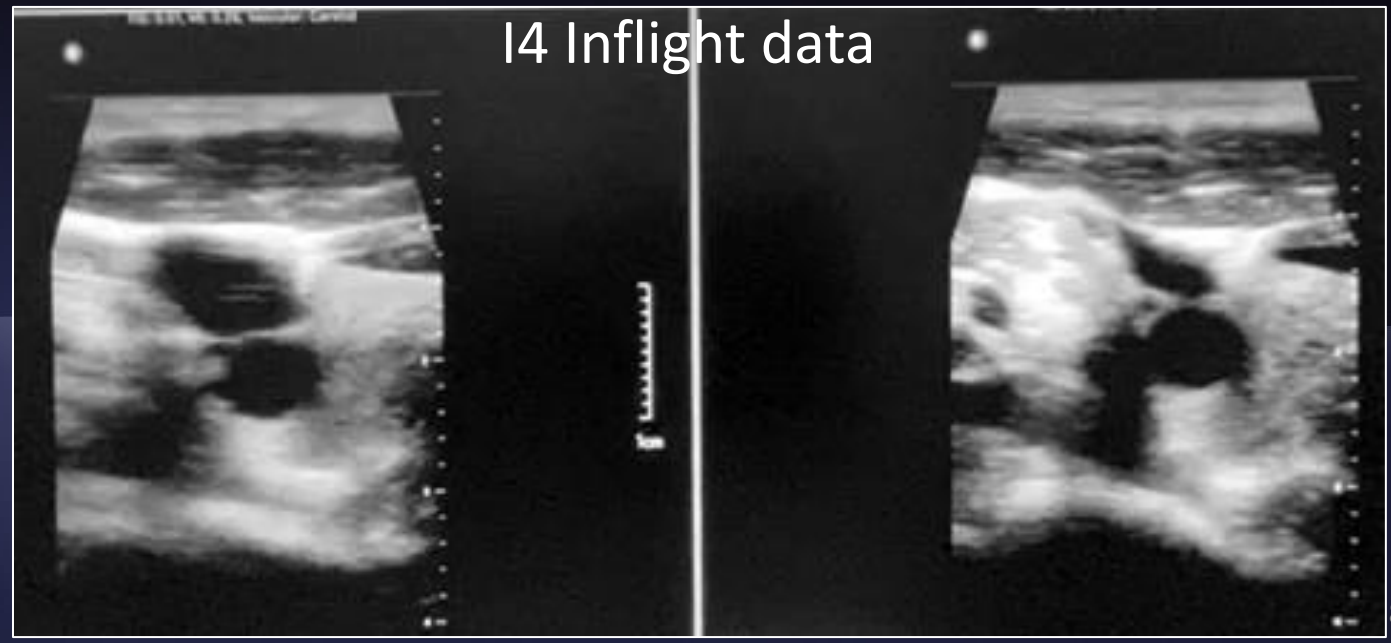
IMPEDANCE THRESHOLD DEVICE (ITD)

- Standardizes inspiratory resistance
- Simple, reusable device
- Relevant intervention for studying IJV flow anomalies
- A potential countermeasure for at-risk subjects (flow stagnation)

NORMAL BREATHING **RESISTANCE BREATHING**

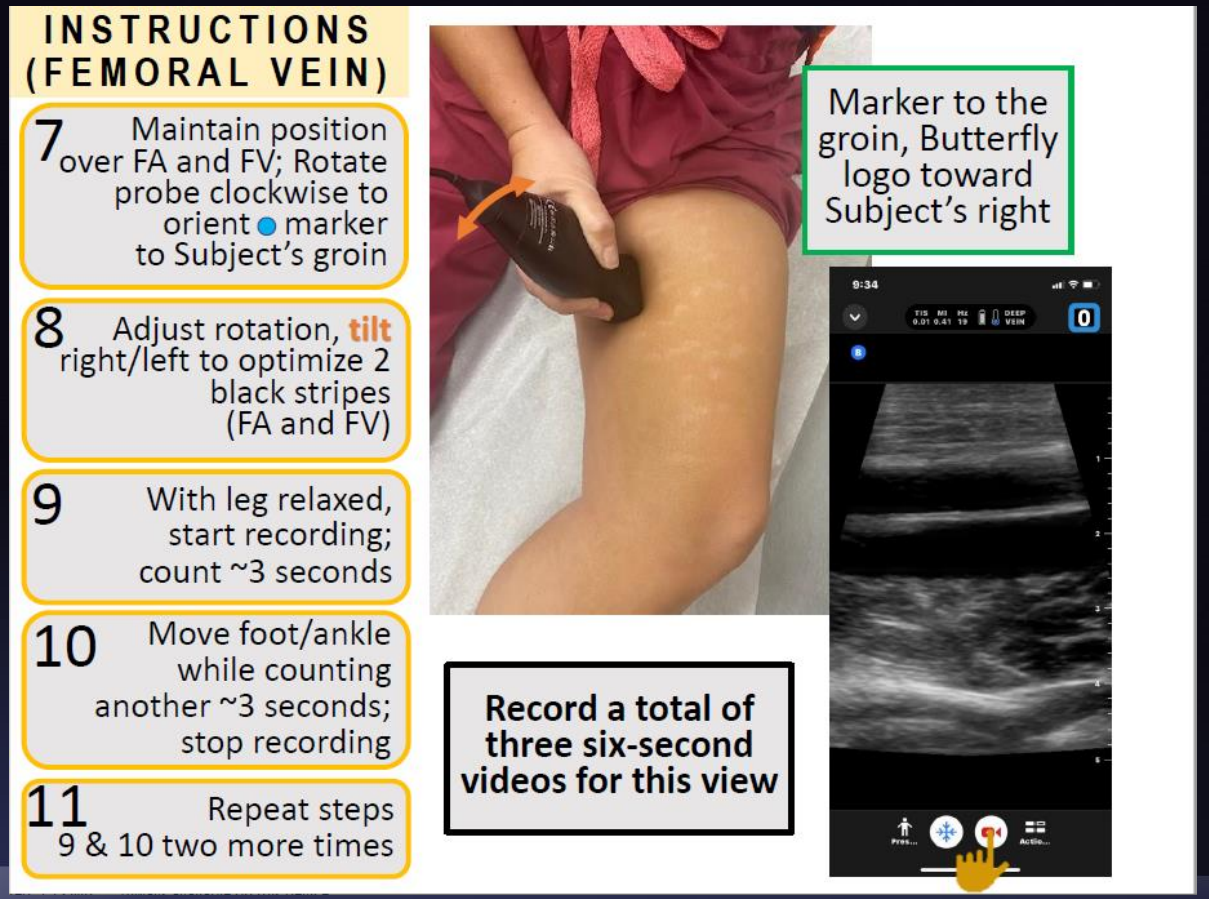


I4 Inflight data



BUBBLE DETECTION

- **Nitrogen offgassing**
  - Informs exploration atmosphere procedures
  - Establishes individual risk profiles
  - Never attempted during spaceflight



KNOWLEDGE MANAGEMENT STUDIES

- **Ground**
  - **COMfORT**
  - **Butterfly iQ evaluations**
  - **Australian Antarctic Division**

CLINICAL OUTCOME METRICS FOR OPTIMIZATION OF ROBUST TRAINING

COMfORT

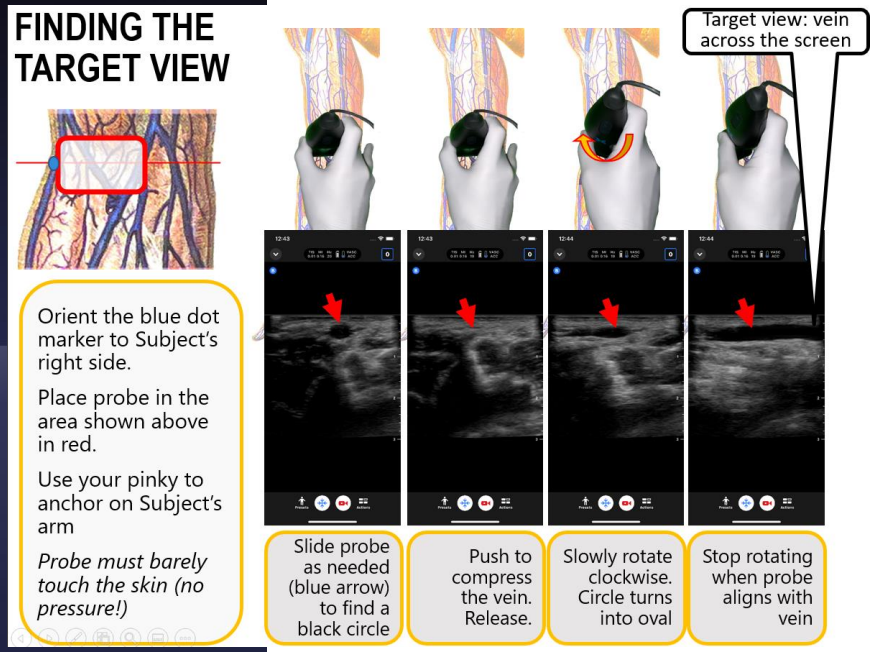
TX

Australian Government

Department of Agriculture, Water and the Environment

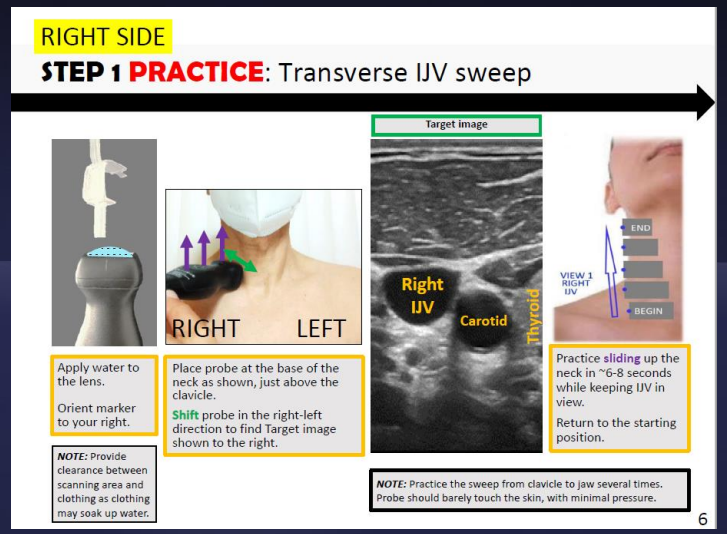
Australian Antarctic Division

AUSTRALIAN ANTARCTIC PROGRAM



KNOWLEDGE MANAGEMENT STUDIES

- **Flight**
  - **AMOS**
  - **Butterfly ISS Tech Demo (1 & 2)**
  - **Inspiration4**
  - **Polaris Dawn**



TRAINING PARADIGM SHIFT

Current

Preflight Medical instruction

7 to 16 hours
6-18 months preflight

In-flight refresher

In-flight procedure

Proposed

Instructional Just In Time (JIT) guidance

Preflight:
-JIT tool familiarization
-Selected procedures trained

Inflight:
-Review and use

KNOWLEDGE MANAGEMENT APPROACH

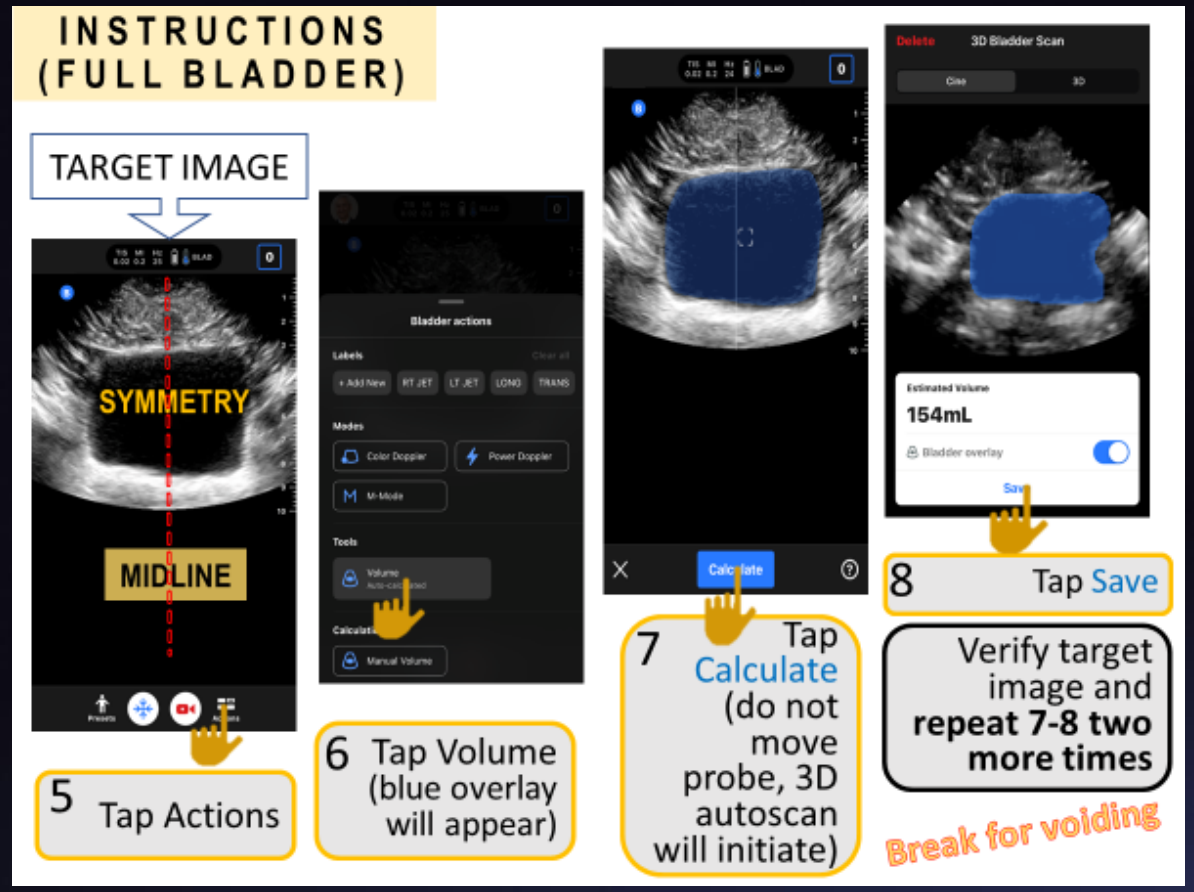
Inspiration4

- all crewmembers minimally trained

Polaris Dawn

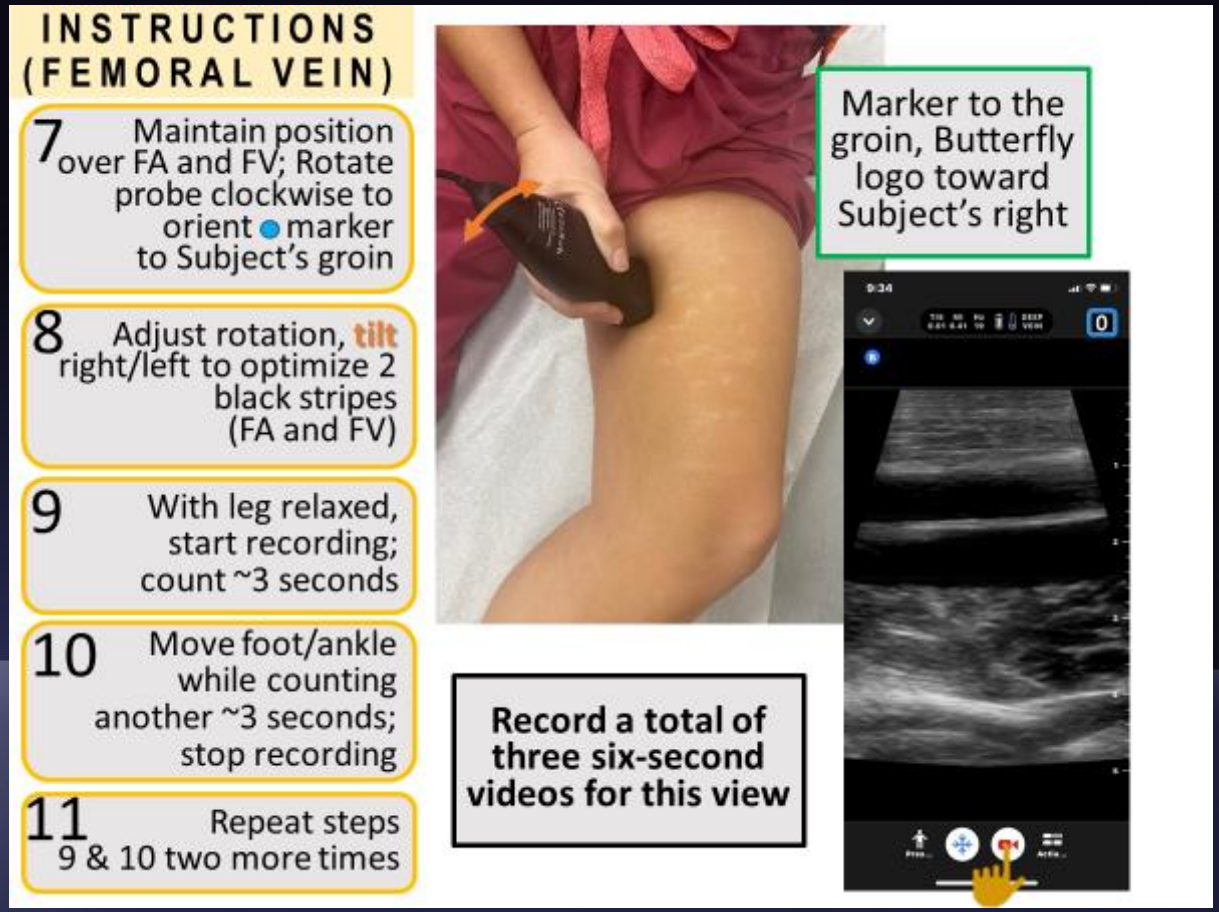
- One repeat crewmember
- One involved in experiment preparation
- Two crewmembers WELL-TRAINED
- Two crewmembers remain UNTRAINED

PROCEDURE GUIDES (.PDF)



Bladder

Bubble Detection



Level Ex Polaris Dawn Procedure Guide

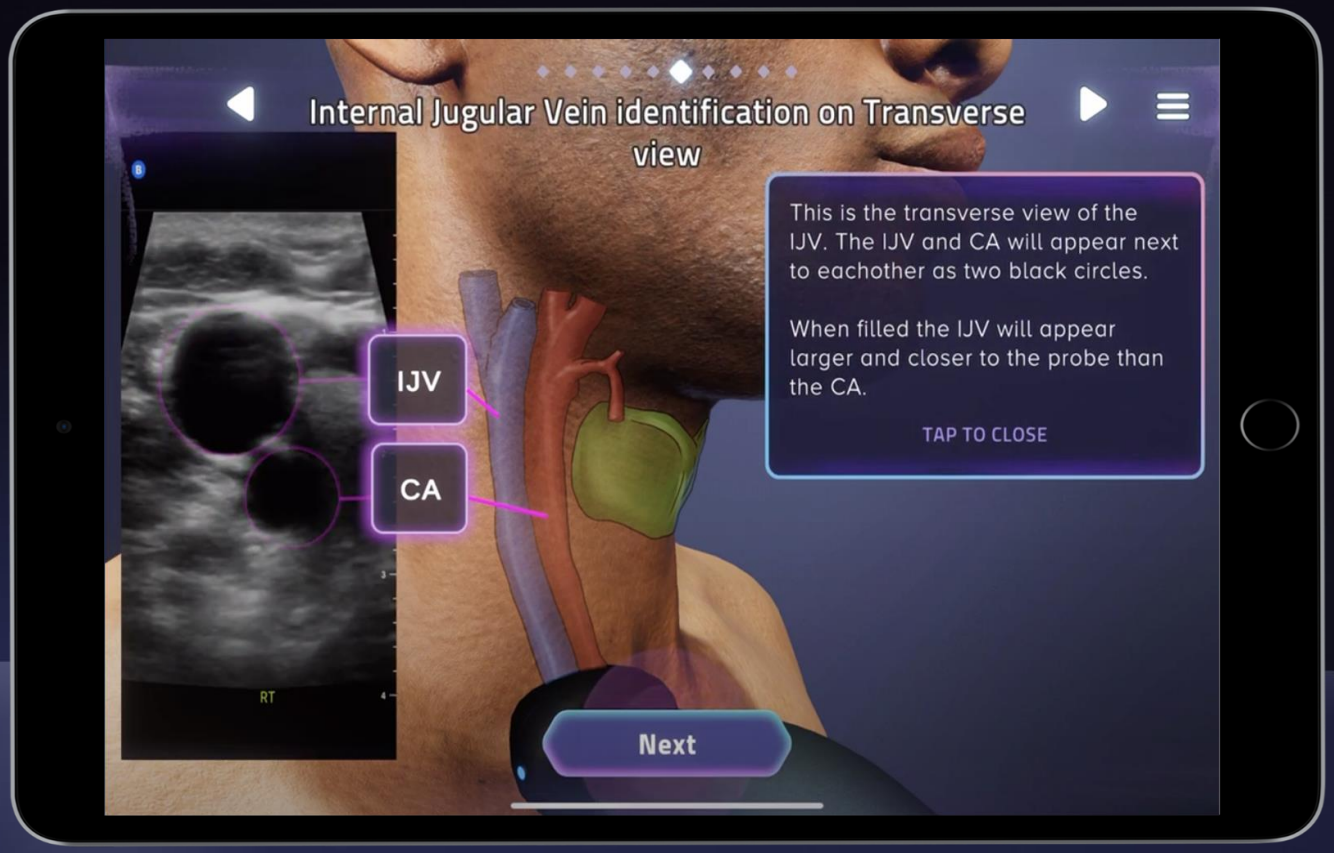
Create a procedural companion for the Polaris Dawn astronaut crew with a specific focus on ultrasound acquisition guidance of the internal jugular vein (IJV) using the Butterfly iQ ultrasound device.

Goals of the Polaris Dawn Ultrasound Study

- Capture information on how microgravity environments influence the human body to support scientific research and future spaceflight missions.
- Prepare and guide crew through IJV ultrasound procedures for scientific data collection.
- Capture information on the use and impacts of interactive training and guidance modalities in spaceflight operations.

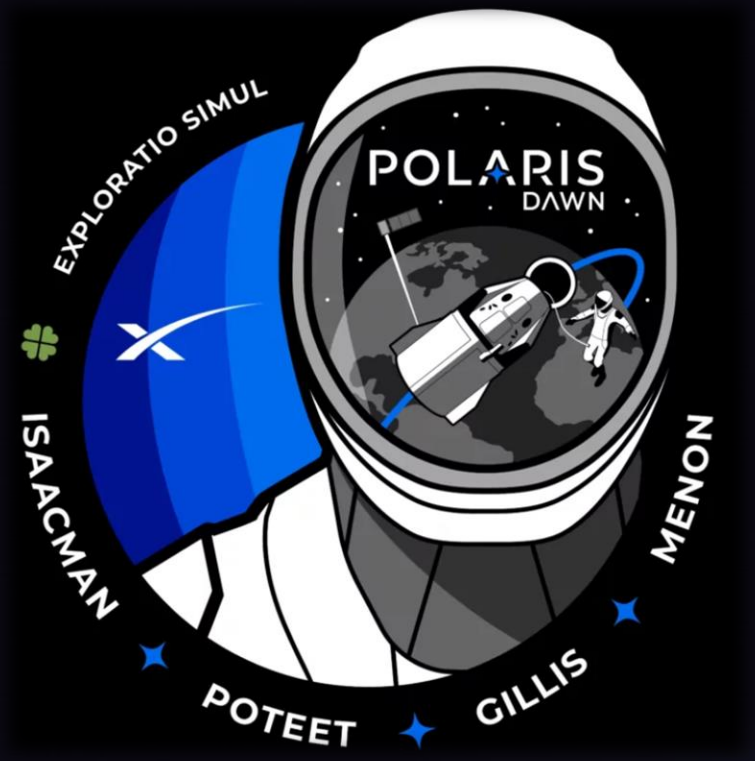
Delivered Features

- 12 modules, compatible for Pre-Flight Training and In-Flight operational guidance
- Intro to ultrasound surveillance with the Butterfly iQ.
- Right and left IJV acquisition:
  - Transverse and longitudinal (B-mode + ITD), doppler, flow spectrum
- Imaging submissions process.



SUMMARY

- Preflight and inflight data
- Physiological analysis (aims 1, 2, & 4)
- Flight images analyzed for quality metrics (aim 3)
- Crew feedback on training methods (aim 3)
- Data can be pooled with other studies (all aims)
  - TRISH CADRE database



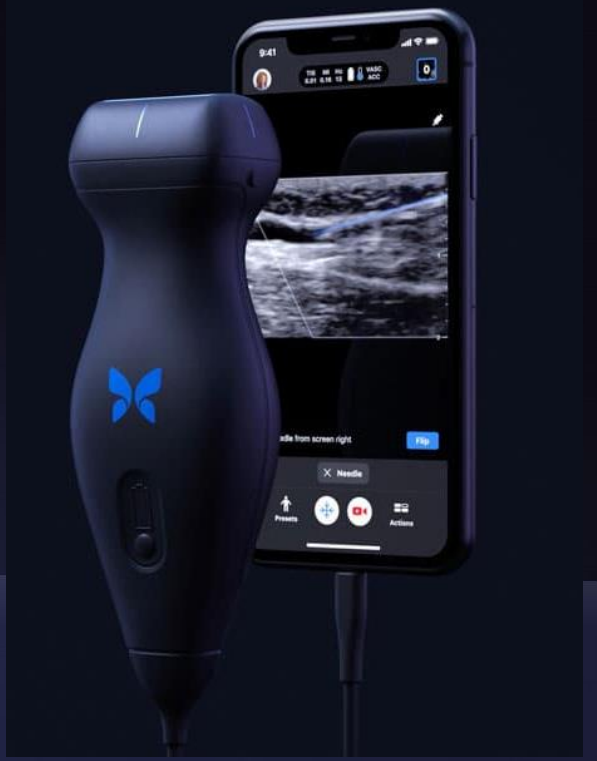
QUESTIONS & DISCUSSION

This research is supported by the Translational Research Institute for Space Health (TRISH)
NASA Cooperative Agreement NNX16AO69A

BACKUP

BACKGROUND

- The Butterfly iQ+ “point-of-care” ultrasound device enables focused investigations on highly constrained missions, thanks to
  - Very small footprint, single-probe
  - Safe, FDA-approved
  - Easy to use
  - Amenable to autonomous use by minimally trained crew
  - Compliant with industry standards for imaging data
  - Use of mobile computing platforms

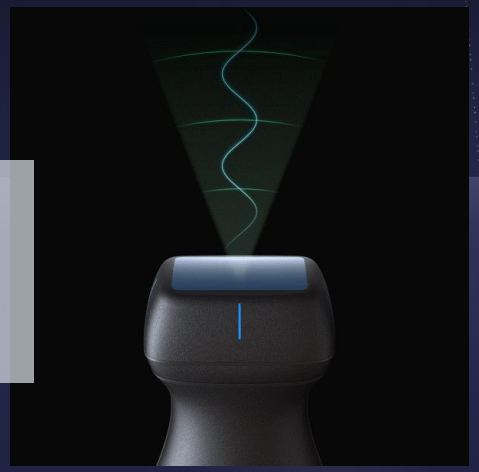


ULTRASOUND INNOVATION

Hardware

- Butterfly IQ+
  - **FDA- and CE- approved, HIPAA compliant**
  - **M: 0.3 kg | V: 0.5 L | Power at charging <15W**
  - >2 hours of continuous operation on battery
  - Single CMUT* probe for all imaging procedures
  - Preset modes for specific imaging applications
  - iPad-based Butterfly iQ app with intuitive operation
  - Compliant with imaging industry standards (“DICOM”)

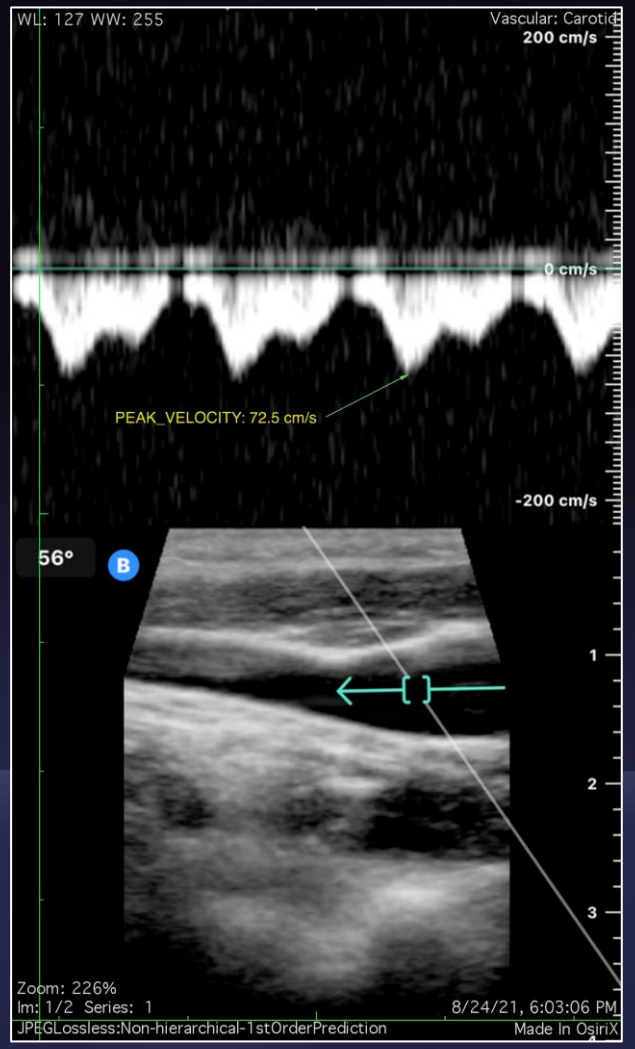
*9,000 – element Capacitive Micro-Machined Ultrasonic Transducer (CMUT)



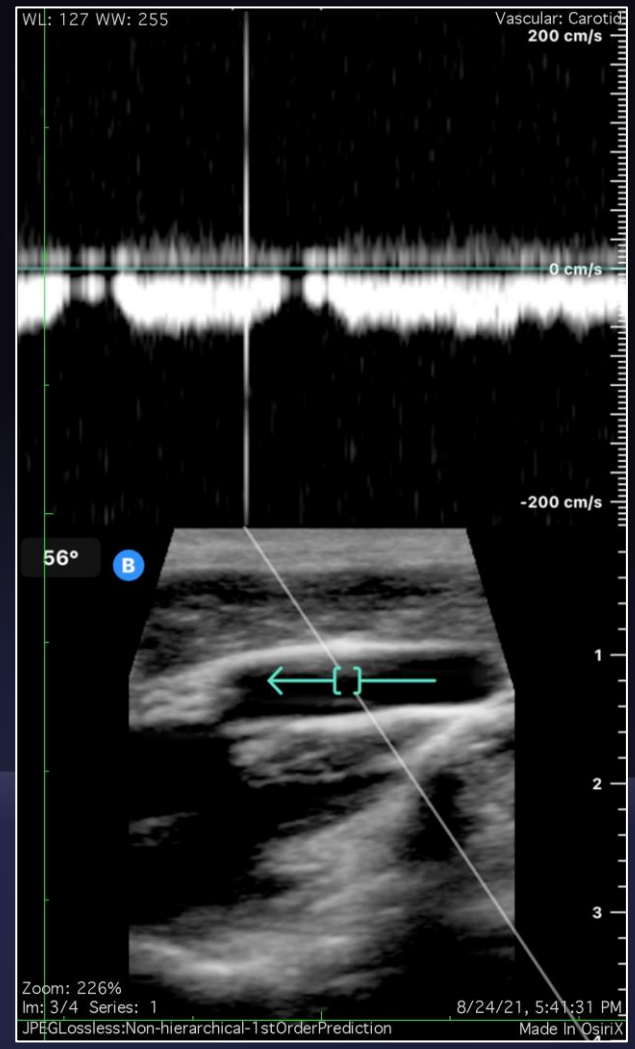
DOPPLER

UNIFORM ANTEGRADE FLOW

“CENTRAL VEIN” TYPE



“PERIPHERALIZED” TYPE



I4: WHAT DID WE LEARN?

- **Autonomous procedures**
  - Skill management approach is the main determinant of success
    - Just-in-time tools – the main source of crew guidance - appear to be the leading limitation (basic – .pdf)
  - Preflight crew training time should be optimized by providing direct interaction with PI teams (in person or remote)
    - Guided practice using same inflight guidance tools, relevant games also a possibility
    - Specific subject matter expertise for immediate feedback
    - Communication of critical conceptual knowledge
    - Procedural tips and pitfalls (anticipated and unanticipated)
  - Concept of a “crew expert” that receives more training may be worth considering
  - Annotation of images may be necessary for more complex procedures
  - Your feedback is CRITICAL to improvement!

I4: WHAT DID WE LEARN?

- **Technical**
  - The single-probe technology and the app performed in microgravity as expected, **including data flow**
- **Physiological**
  - Unique structural and functional data from early microgravity phase
    - Limited statistical options due to a small number of subjects and subject variability
    - ITD appears to be effective in microgravity
    - IJV engorgement appears to be more pronounced in early spaceflight
    - Post-void urine residual appears to be normal in spaceflight

I4: OVERALL CONCLUSIONS

- Inspiration4 laid the foundation for new research and development trends
    - Nimble approach to rapid experimentation cycles
    - Efficiency in resource utilization
- Open questions in space physiology and medicine **can** be answered by “minimalist” experiments using latest technology with a small footprint
- Results show where we need to improve procedures, which contributes to the development of medical imaging capability for future human space flight in highly constrained environments

ULTRASOUND INNOVATION

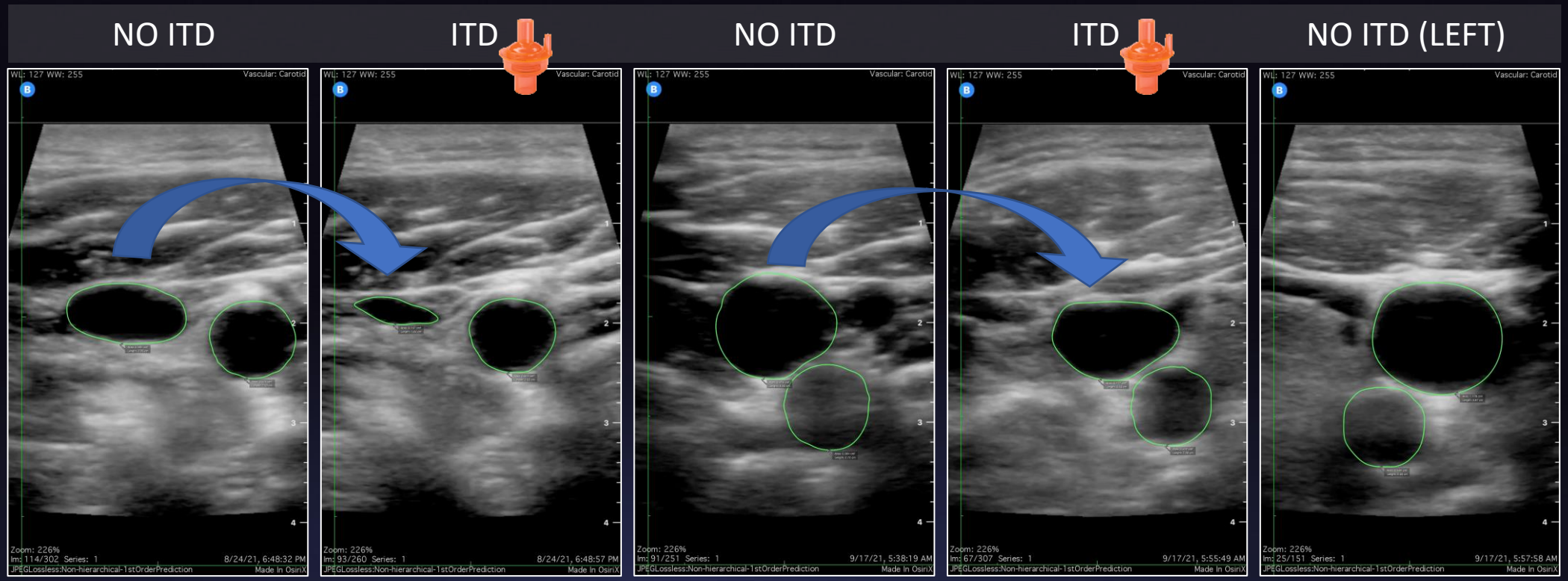
Hardware

Impedance Threshold Device (ITD)

- **FDA approved (for certain acute care settings)**
- **Mass: 32 g**
- Simple mechanical valve
- With inhalation, creates ~7.0 cmH_2O negative pressure in the chest
- Facilitates venous blood return to the heart

SAMPLE: RIGHT IJV CROSS-SECTIONAL AREA

GROUND (supine) | **FLIGHT DAY 2**



Area (cm^2)	**0.58**	0.53	**0.15**	0.5	**0.98**	0.58	**0.78**	0.51	0.53	**1.18**
Perimeter (cm)	2.95	2.58	2.53	2.53	3.55	2.72	3.3	2.56	2.6	3.87

ULTRASOUND INNOVATION

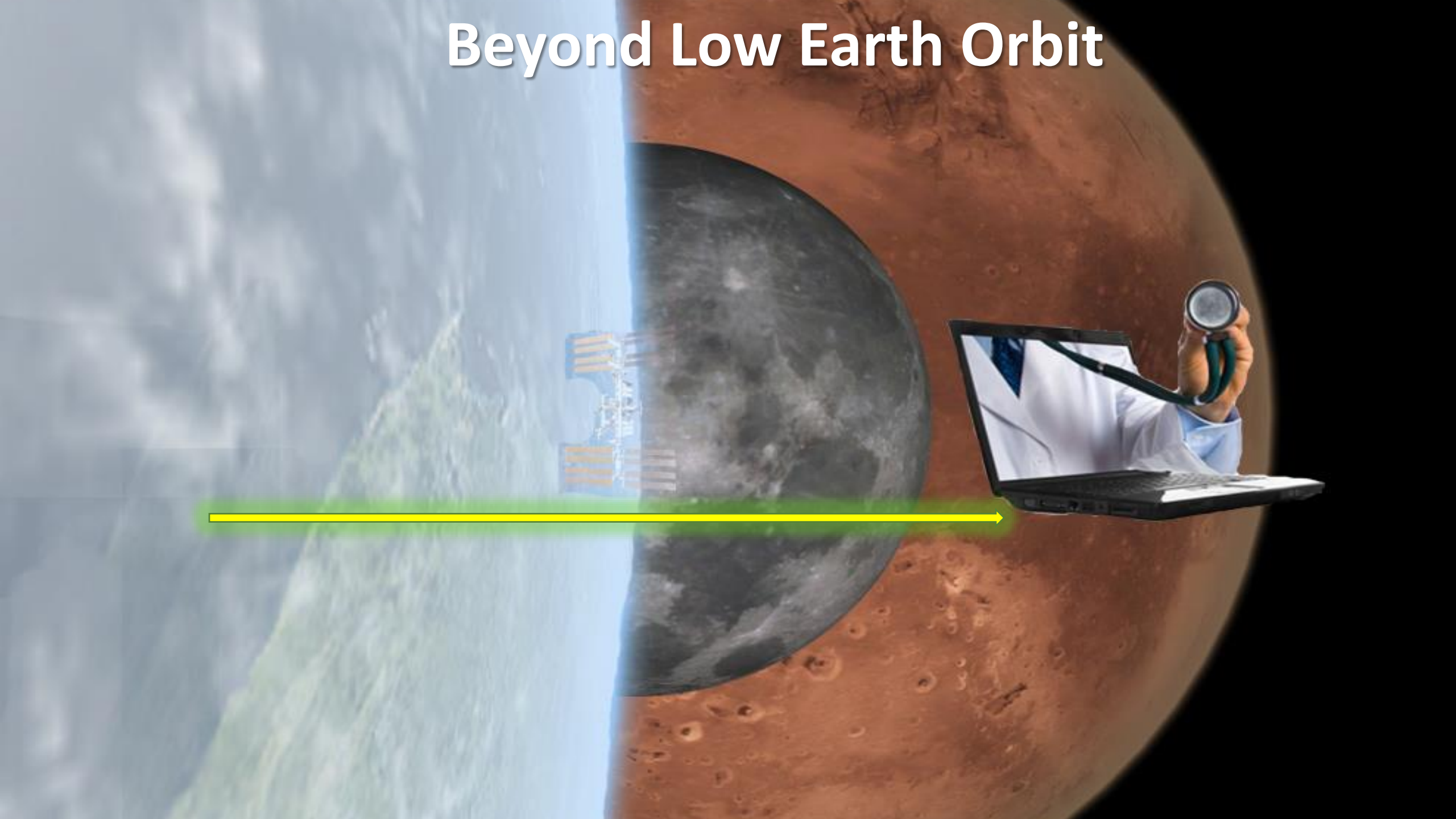
Flight Schedule/Methods

Each crewmember	FD1	FD2	FD3	FD4	FD5	Total time
Bladder (15 min)	X	X	-	-	-	30
Major Veins (30 min)	X	X			X	90
Major Veins Reduced (5 min)	-	-	-	X (2-5 times)		10-25
Bubble detection (15 min)	X	X	X	-	-	45

Biggest practical concern is battery charging time- primarily iQ+ but also for iPads/iPhones

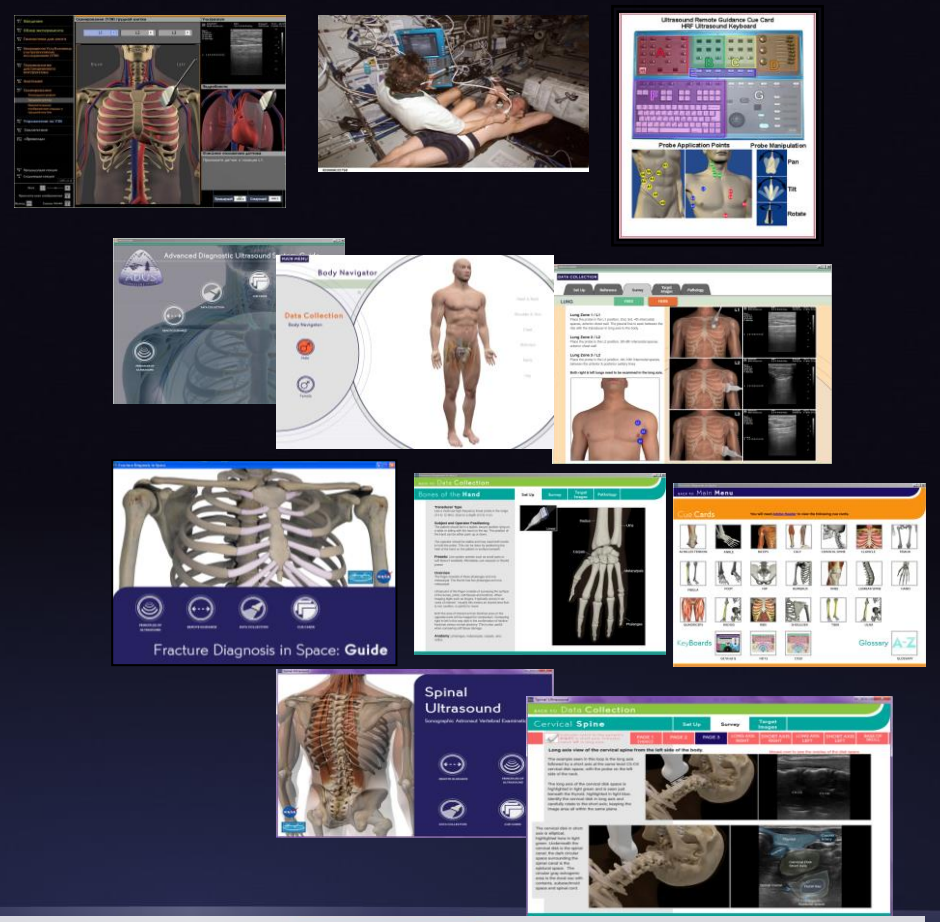
Now: ISS Operations

Beyond Low Earth Orbit



Software Heritage

- ADUM
  - on ISS 2004-2005
- Catalog
  - ground study 2007-2011
- Fracture
  - ground study 2008-2011
- Spinal Ultrasound
  - on ISS 2013-present
- COMfORT
  - 2016-17



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